

1993

Comparison of Total Body Water Estimates From ^{18}O and Bioelectrical Response Prediction Equations

Linda H. Barrows,
L. Daniel Inners,
and Marcella D. Stricklin
KRUG Life Sciences
Houston, Texas

Peter D. Klein
and William W. Wong
Children's Nutrition Research Center
at Baylor College of Medicine
Houston, Texas

Steven F. Siconolfi
Lyndon B. Johnson Space Center
Houston, Texas



National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Program

CONTENTS

	Page
INTRODUCTION	1
METHODS	1
RESULTS	4
CONCLUSION	6
REFERENCES	6

TABLES

		Page
1	<i>Subject characteristics (mean \pm SD)</i>	1
2	<i>Bioelectrical response prediction equations used to estimate TBW</i>	3
3	<i>Total body water estimates from three bioelectrical response prediction equations and hydrostatically derived FFM compared to total water measured from ^{18}O ($n = 27$)</i>	5

FIGURES

1	Bioelectrical resistance test conducted in the supine position. Electrodes being used for measuring—found on the subject's right hand and left foot—are covered with cloth to keep the temperature constant	2
2	Hewlett-Packard Precision LCR meter and YSI skin temperature probe apparatus	3
3	Body volume determination by hydrostatic weighing using a snorkel-like device and tidal breathing	4
4	Comparison (mean \pm SD) of TBW prediction methods with ^{18}O	5

INTRODUCTION

Measurement of total body water (TBW) during extended-duration spaceflight may be performed to evaluate exercise and cardiovascular countermeasures to microgravity-induced deconditioning. Quantification of TBW can be performed through the use of water enriched with a stable isotope of oxygen, ^{18}O [1,2]. A sample of H_2^{18}O is ingested orally and, after 3 to 5 hours of equilibration with the body's water compartments, saliva samples are obtained to measure H_2^{18}O dilution. This method of TBW measurement is noninvasive, requires little effort on the part of the subject, and has a precision of 0.8-1.5% when compared to serum samples [1]. Traditionally, isotope dilution using deuterated ($^2\text{H}_2\text{O}$) or tritiated ($^3\text{H}_2\text{O}$) water has been used as the reference for TBW measurement. Use of deuterated water, however, can cause metabolic side effects when given in high doses; and tritiated water is radioactive, which limits its use in many circumstances. Analysis of hydrogen isotope dilution also requires use of very precise and expensive spectrometric equipment [2]. Finally, hydrogen isotopes can overestimate the TBW measurement due to hydrogen exchange with protein. The use of ^{18}O , a naturally occurring stable isotope of oxygen, is much more desirable than the use of hydrogen isotopes; but it is not without drawbacks, which are: (1) expensive generation (\$500-\$1000/dose), (2) limited availability (i.e., approximately 1 year to obtain), and (3) need for costly spectrometric analyzers to evaluate the saliva samples. For these reasons, many clinical and research facilities estimate TBW indirectly through hydrostatic weighing techniques. Total body immersion is used to calculate the body density

from which percent body fat and fat-free mass (FFM) are derived. TBW represents a fixed fraction (73.2%) of FFM [7].

Bioelectrical responses have been shown to estimate human body composition accurately [3-6]. Bioelectrical response devices measure resistance (R) and reactive capacitance (reactance) responses to an excitation current of 800 μA at a signal frequency of 50-120 kHz. The subthreshold current is applied through electrodes at the wrist and ankle, and bioelectrical measurements are made immediately. A clear linear relationship ($r = -0.86$) exists between TBW (from deuterium-labeled water) and bioelectrical resistance [5]. This relationship is strengthened when TBW is correlated with height (Ht) and bioelectrical resistance (R) in the factor Ht^2/R [3,5].

Numerous prediction methods exist for estimating body composition and TBW. Identification of a method that is rapid, accurate, and cost-effective is necessary so that the procedure may be used during extended-duration spaceflight to monitor countermeasure therapy. The purpose of this investigation was to compare TBW estimates from three established bioelectrical response prediction equations [2,3,8] with two standard methods—hydrostatically derived FFM and ^{18}O .

METHODS

Twenty-seven subjects (14 females and 13 males) were recruited through the NASA Health Screening Facility at the NASA/Johnson Space Center and gave written informed consent to participate in the study (Table 1).

TABLE 1. *Subject characteristics (mean \pm SD)*

n	27	
Mean Age (yr)	32	\pm 6
Mean Height (cm)	168.5	\pm 6.0
Mean Weight (kg)	67.8	\pm 12.2
Mean Body Fat (%)	21.0	\pm 6.7

All testing was completed between 7:00 a.m. and 1:00 p.m. on the same day. Subjects were asked to fast for at least 4 hours, with no consumption of caffeine or alcohol within 24 hours of testing. Upon arrival, a background saliva sample was collected to establish existing levels of ^{18}O in the body. Subjects then were given a bagel and juice prior to ingesting 40-45 g of H_2^{18}O (6-7 g of ^{18}O). To ensure that the entire amount of ^{18}O was ingested, the bottle containing the H_2^{18}O was rinsed twice with approximately 50 mL of tap water and was given to the subject to drink. Subjects then gave approximately 5 mL of saliva at 3, 4, and 5 hours after initial H_2^{18}O consumption. Saliva samples were immediately frozen and later analyzed by the Stable Isotope Laboratory, Children's Nutrition Research Center at the Baylor College of Medicine.

Bioelectrical response testing was completed between the 3- and 4-hour ^{18}O saliva collection times. Skin sites on the distal surface of the metacarpals and metatarsals, between the medial and lateral malleoli of the ankle, and between the distal prominences of the radius and ulna, were cleansed with alcohol before applying four silver/silver chloride ECG electrodes (Fig. 1).

Tetrapolar bioelectrical resistance readings were taken immediately upon resuming the supine position, and measurements were made of the subject's right side. Bioelectrical resistance responses to input frequencies of 50-300 kHz were simultaneously obtained from a modified 4284A Hewlett-Packard Precision LCR Meter (Fig. 2).

Three bioelectrical response prediction equations were used to estimate TBW (Table 2).



FIG. 1. Bioelectrical resistance test conducted in the supine position. Electrodes being used for measuring—found on the subject's right hand and right foot—are covered with cloth to keep them temperature constant.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

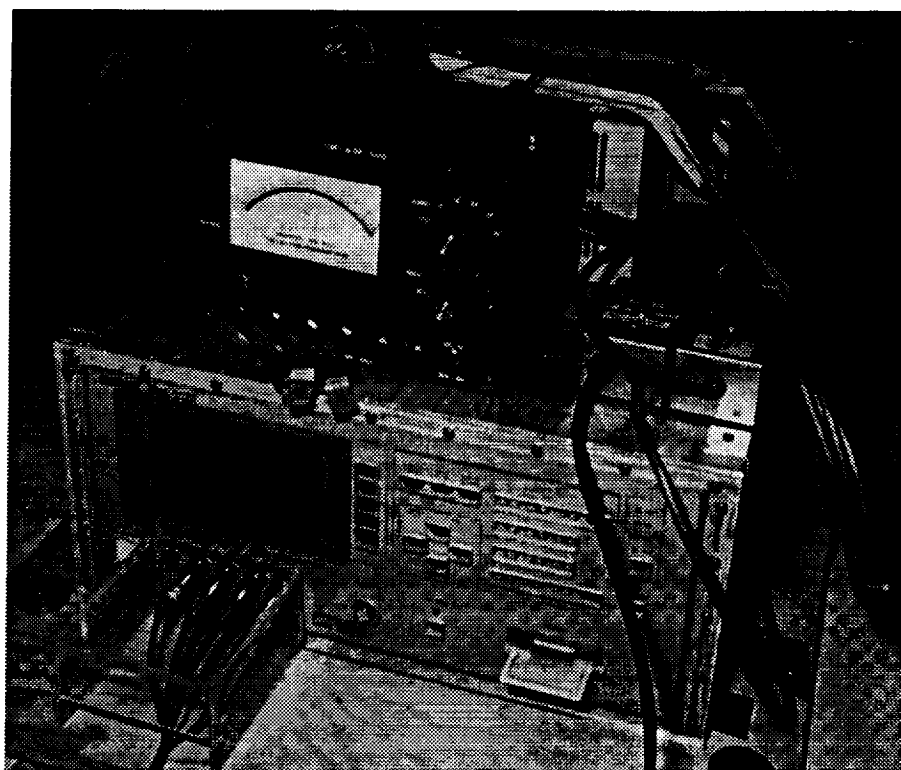


FIG. 2. Hewlett-Packard Precision LCR meter and YSI skin temperature probe apparatus.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

TABLE 2. *Bioelectrical response prediction equations used to estimate TBW*

1. Lukaski & Bolonchuk [4]

$$TBW (L) = 0.337 \cdot (Ht^2/R) + 0.14 \cdot Wt - 0.08 \cdot Age + 2.9 \cdot Gender + 4.65$$

where R at 50 kHz
 Gender: Male = 1, Female = 0
2. Kushner & Schoeller [3]
 Males: $TBW (L) = 0.396 \cdot (Ht^2/R) + 0.143 \cdot Wt + 8.399$
 Females: $TBW (L) = 0.382 \cdot (Ht^2/R) + 0.105 \cdot Wt + 8.315$

where R at 50 kHz
3. Segal et al. [8]

$$TBW (L) = 3.43 + 0.14 \cdot Wt + 0.45 \cdot (Ht^2/R)$$

where R at 100 kHz

Body density determination through hydrostatic weighing was conducted immediately after ingesting the $H_2^{18}O$. Each subject was completely submerged in a tank of water (30-35°C) and was allowed to perform normal tidal breathing through a snorkel-like device (Fig. 3).

Ten maximal exhalations were performed, at which time weights were recorded. Body volume was corrected for lung residual volume using an oxygen dilution technique [9] that was performed at the end of the test period. Percent body fat [10], FFM, and TBW (73.2% of FFM) were then calculated from body density using a two-compartment model.

TBW (kg) mean, standard deviation (SD), and standard error of estimate as a percent of the ^{18}O mean (SEE), were calculated for TBW

measurements from ^{18}O , FFM from hydrostatic weighing, and the three bioelectrical response prediction equations (Table 2). Pearson product-moment correlation coefficients (r) were calculated to determine the relationship between each method and ^{18}O . A repeated measures MANOVA with post-hoc Dunnett's Test was used to determine significant differences between bioelectrical response prediction and ^{18}O .

RESULTS

The equation from Segal et al. [8] yielded mean TBW estimates that were significantly ($p < 0.05$) greater than the mean TBW measurement given by ^{18}O . The bioelectrical response prediction equation from Lukaski &

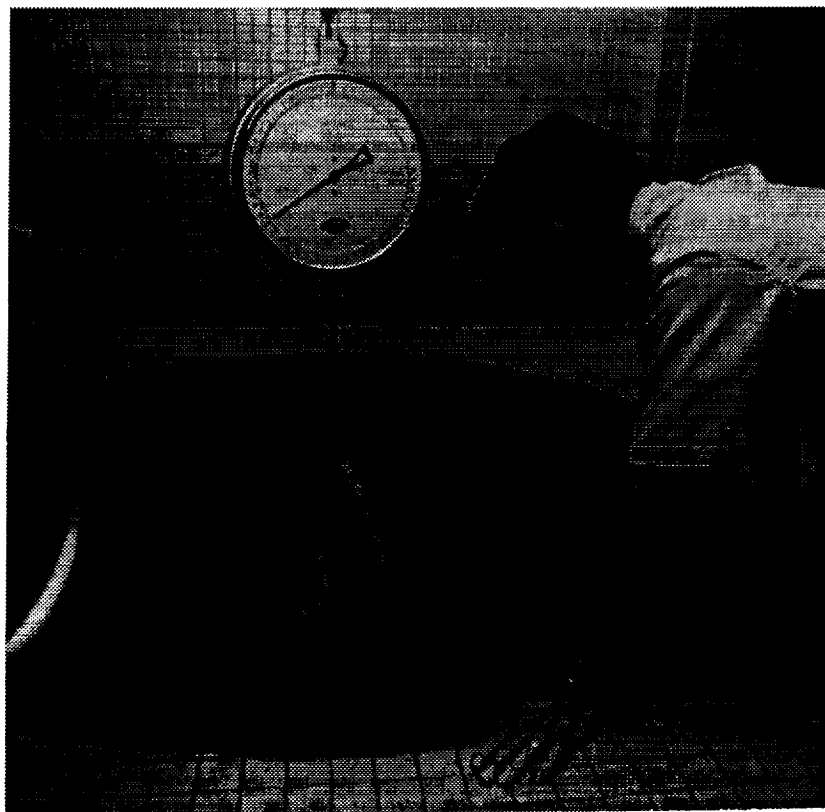


FIG. 3. Body volume determination by hydrostatic weighing using a snorkel-like device and tidal breathing

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Bolonchuk [4] significantly ($p < 0.05$) under-predicted TBW. TBW estimates from FFM and the bioelectrical response prediction equation of Kushner & Schoeller [3] were not significantly ($p > 0.05$) different than those given by ^{18}O (Table 3, Fig. 4). Standard errors identified through regression analyses were, however, higher for all bioelectrical response prediction equations when compared to those derived from FFM (Table 3). Strong correlation coefficients

were found between each prediction method and ^{18}O .

Findings reported here are for all subjects combined (Table 3). When the findings for males ($n = 13$) and females ($n = 14$) were analyzed separately, the mean, SD, SEE, and r were altered but statistical findings were unchanged. Results are, therefore, presented for all 27 subjects.

TABLE 3. Total body water estimates from three bioelectrical response prediction equations and hydrostatically derived FFM compared to total water measured from ^{18}O ($n = 27$)

Method	Mean	SD	r	SEE (%)
^{18}O	39.29	7.31	--	--
FFM	39.16	7.44	0.98	3.5
Kushner & Schoeller [3]	39.81	7.96	0.93	6.7
Lukaski & Bolonchuk [4]	32.81*	7.09	0.94	6.4
Segal et al. [8]	41.56*	8.22	0.93	7.2

*Significantly, ($p < 0.05$) differs from ^{18}O .

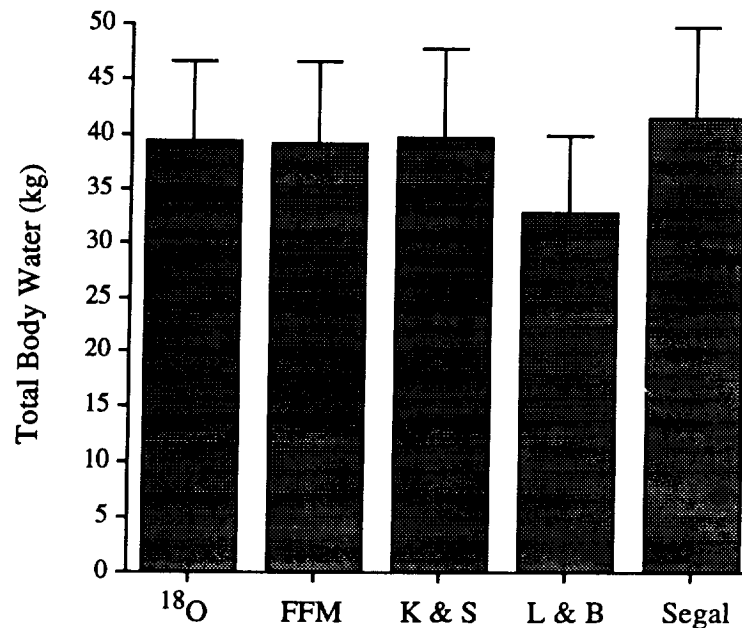


FIG. 4. Comparison (mean \pm SD) of TBW prediction methods with ^{18}O

CONCLUSION

Bioelectrical response testing requires minimal equipment and effort, and produces results quickly. If accurate, this method would be ideal for use during spaceflight to monitor hydration status and perhaps improve countermeasure application and orthostatic tolerance upon return to one-g. The bioelectrical response prediction equation from Kushner & Schoeller [3] provided the most valid measure of TBW in this study when compared to the reference value given by ^{18}O . The Kushner & Schoeller equation, unlike

the other two bioelectrical response prediction equations examined, uses separate numerical constants depending upon gender. All three prediction equations had greater variability in measuring TBW than that found with FFM, which is commonly used in laboratories as a reference to assess body composition (Table 3). It is suggested that, before using the impedance method to measure TBW during spaceflight, other bioelectrical response prediction equations with lower variability should be identified.

REFERENCES

- [1] SCHOELLER, D. A., W. DIETZ, E. VAN SANTEN, AND P. D. KLEIN. Validation of saliva sampling for total body water determination by H_2^{18}O dilution. *Am. J. Clin. Nutr.* 35:591-4, 1982.
- [2] SCHOELLER, D. A., E. VAN SANTEN, D. W. PETERSON, W. DIETZ, J. JASPAN, AND P. D. KLEIN. Total body water measurement in humans with ^{18}O and ^2H labeled water. *Am. J. Clin. Nutr.* 33:2686-93, 1980.
- [3] KUSHNER, R. F. AND D. A. SCHOELLER. Estimation of total body water by bioelectrical impedance analysis. *Am. J. Clin. Nutr.* 44:417-24, 1986.
- [4] LUKASKI, H. C. AND W. W. BOLONCHUK. Estimation of body fluid volumes using tetrapolar bioelectrical impedance measurements. *Aviat. Space Environ. Med.* 59:1163-69, 1988.
- [5] LUKASKI, H. C., P. R. JOHNSON, W. W. BOLONCHUK, AND G. I. LYKKEN. Assessment of fat-free mass using bioelectrical impedance measurements of the human body. *Am. J. Clin. Nutri.* 41:810-17, 1985.
- [6] LUKASKI, H. C., W. W. BOLONCHUK, C. B. HALL, AND W. A. SIDERS. Validation of tetrapolar bioelectrical impedance method to assess human body composition. *J. Appl. Physiol.* 60(4):1327-32, 1986.
- [7] LUKASKI, H. C. Methods for the assessment of human body composition: Traditional and new. *Am. J. Clin. Nutr.* 46:537-56, 1987.
- [8] SEGAL, K. R., S. BURASTERO, A. CHUN, P. CORONEL, R. N. PIERSON, AND J. WANG. Estimation of extracellular and total body water by multiple-frequency bioelectrical-impedance measurement. *Am. J. Clin. Nutr.* 54:26-29, 1991.
- [9] WILMORE, J. R. A simplified method for determination of residual lung volumes. *J. Appl. Physiol.* 27:96-100.
- [10] BROZEK, J. F., J. T. GRANDE, AND A. ANDERSON. Densitometric analysis of body composition: Revision of some quantitative assumptions. *Ann. NY Acad. Sci.* 10:113-40, 1963.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE April 1993	3. REPORT TYPE AND DATES COVERED Technical Paper		
4. TITLE AND SUBTITLE Comparison of Total Body Water Estimates From ^{18}O and Bioelectrical Response Prediction Equations			5. FUNDING NUMBERS	
6. AUTHOR(S) Linda H. Barrows, L. Daniel Inners, Marcella D. Stricklin, Peter D. Klein, William W. Wong, and Steven F. Siconolfi				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Medical Sciences Division Space Biomedical Research Institute National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, TX 77058			8. PERFORMING ORGANIZATION REPORT NUMBER S-696	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING / MONITORING AGENCY REPORT NUMBER NASA TP-3299	
11. SUPPLEMENTARY NOTES Barrows, Inners, and Stricklin: KRUG Life Sciences, Houston, TX; Klein and Wong: Children's Nutrition Research Center at Baylor College of Medicine, Houston, TX; Siconolfi: Lyndon B. Johnson Space Center, Houston, TX.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category 52			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Identification of an indirect, rapid means to measure total body water (TBW) during spaceflight may aid in quantifying hydration status and assist in countermeasure development. Bioelectrical response testing and hydrostatic weighing were performed on 27 subjects who ingested ^{18}O , a naturally occurring isotope of oxygen, to measure true TBW. TBW estimates from three bioelectrical response prediction equations and fat-free mass (FFM) were compared to TBW measured from ^{18}O . A repeated measures MANOVA with post-hoc Dunnett's Test indicated a significant ($p < 0.05$) difference between TBW estimates from two of the three bioelectrical response prediction equations and ^{18}O . TBW estimates from FFM and the Kushner & Schoeller (1986) equation yielded results that were similar to those given by ^{18}O . Strong correlations existed between each prediction method and ^{18}O ; however, standard errors, identified through regression analyses, were higher for the bioelectrical response prediction equations compared to those derived from FFM. These findings suggest (1) the Kushner & Schoeller (1986) equation may provide a valid measure of TBW, (2) other TBW prediction equations need to be identified that have variability similar to that of FFM, and (3) bioelectrical estimates of TBW may prove valuable in quantifying hydration status during spaceflight.				
14. SUBJECT TERMS body fluids, total body water (TBW); bioelectricity, bioelectric response prediction equations; adipose tissues, fat-free mass (FFM)			15. NUMBER OF PAGES 12	
			16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	